# Design and Implementation of User Interactive Wireless Smart Home Energy Management System

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*Abstract*— **Electricity usage is increasing day by day due to the changing life style of home user and an increase in appliances in the home area network. Our proposed home energy management system for home users will monitor, manage and control the usage of home appliances, by reducing the monthly electricity bill The proposed wireless architecture consists of an appliance control device called Wireless Enabled Electricity Manager (WEEMAN) installed next to a switch board or every device/ appliance in a room. The central node called smart meter runs an algorithm called Availability Based Energy Management algorithm. This algorithm learns about the previous usage patterns of the appliances, collects real time power consumption of appliances from WEEMAN to generate efficient energy load patterns. The highpoint of the algorithm is that it gives an option for the user to set their monthly current bill and pro-actively control the operation of all the appliances according to the amount. We have developed a hardware test bed consisting of WEEMAN connected to some selected appliances and a smart meter to control every WEEMAN.**

***Keywords— Home Energy Management, Home Area Network, Wireless Sensor Network, Smart Gird***

## I. INTRODUCTION

The electric power consumption (Kwh) in India was 689,537,000,000 as of 2011 and earlier it was 156,400,000,000 in the year 1990[5].The main reason for this is due to an increase in electronic as well as electrical appliances in the home area network (HAN). When we compare the energy usage between 1990 to 2011, we can hardly find a home without a TV, washing machine, refrigerator etc. Major electricity consumption among home appliances are lighting devices, that uses about 30 percent of electrical energy followed by refrigerators, fans, and electric water heaters etc. Figure 1 show comparison of electricity usage of various house hold appliances over the past 5 years and expected proportionate demand for power supply in the coming years.

As per the statistics in figure 1, we can expect a huge demand for power supply from the home environment especially for entertainment and heating/cooling appliances. There is a huge gap between the available and generated power supply, due to factors such as global warming and modernization. Utility companies have to search for alternatives to avoid harnessing natural resources. Also, using natural resources is not a long term solution since we have a very limited resource as well as a huge cost of converting the resource into usable electrical energy. So there is an increased need to manage, balance, and use power supply.

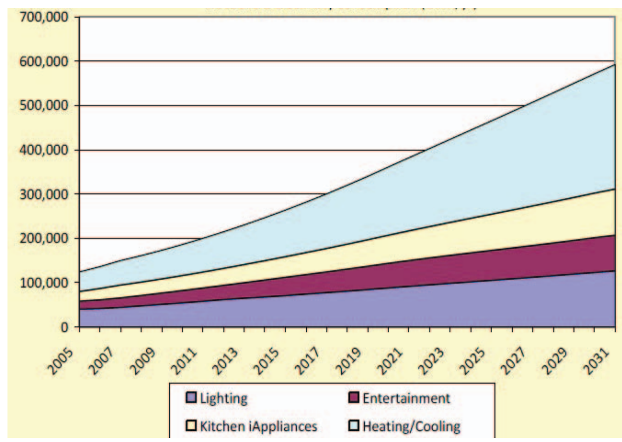


Figure 1 .Year wise energy consumption of appliances [5]

The main challenge in a smart home is to implement a Home Area Network (HAN) solution to interconnect appliances and offer smart services for energy management, comfort, and automation. Energy management has pivotal significance among those services. This energy management technique could be used during different times for different appliances based on consumers' behavior. The table shows the usage of appliance based on different times on a sunny weekday. There will be some changes for the weekend days, mainly during 10 am – 4 pm. Table 1 shows that the need of an appliance changes based on the consumers nature of work, behavior and temperature. For example, temperature changes may affect (increase/decrease) the usage of heating /cooling appliances. If it is a balmy day the usage of cooling appliances is higher and on a cold, rainy day heating appliances would be used. Power management technique observes these facts for proper scheduling of home appliances. This management technique keenly observes temperature changes by incorporating sensor module to sense the real time temperature as well as light values to make acceptable decisions.

The proposed power management system works in a wireless mesh network with WEEMAN as a node .The availability management algorithm is designed to stay close to the user and learns the common behavioral patterns inside the house irrespective of personal identity.

Table 1. Time based usage of appliances [2]

| Appliances | Timings | | | |
|---|---|---|---|---|
| | 6 am -10 am | 10 am-4 pm | 4 pm-10 pm | 10 pm – 6 am |
| Lighting | 10 % | 5 % | 40 % | 7 % |
| Entertainment | 30 % | 30 % | 25 % | 10 % |
| Kitchen | 50 % | 30 % | 20 % | 3% |
| Heating | 10 % | 5 % | 5 % | 2 % |
| Cooling | 5 % | 30 % | 10 % | 78 % |

The algorithm will automatically learn the importance of an appliance at home, based on frequent usage Also it groups the appliances based on the different priority set by the user and algorithm. The key emphasize of the management scheme is that it proactively controls all appliances based on the option given by the user and budgets the amount for the following month's electricity bill. This feature will mainly focus on those consumers who want to manage their monthly budget.

This smart architecture helps the consumer in decreasing the electricity bill as well as enabling the utility company to manage the discrepancy in the generated and demanded electric power. The proposed architecture enables consumer participation in electricity management using wireless communication devices. It gives flexibility to the consumers in switching on a high priority load by switching off one or a set of low priority loads without affecting the comfort level of the consumers. The IEEE 802.15.4[6] low rate wireless personal area network is one of the protocols most suitable for wireless sensor networks**.** This has MAC/PHY [7] layers of IEEE 802.15.4, that has a protocol for well-known sensor nodes, e.g. MICAz TelosB motes, etc. Its most frequently cited characteristics are low power consumption, long battery life, low product cost, and open standards. Mesh networking of ZigBee [8] also makes IEEE 802.15.4 attractive in home automation.

The paper is organized as follows: Section 2 describes the work related to this field. Section 3 and 4 includes the system architecture and the design of the algorithms. Section 5 discusses the experimentation setup followed by conclusion.

## II. Related Works

Jinsung Byun and Sehyun Park describes a self adapting intelligent system [1] created with mainly two components called Self adapting Intelligent Sensor (SIS) and Self adapting Intelligent Gateway (SIG).The Wireless Sensor Network's life time and system resource management can be improved with the help of the proposed Energy Efficient Self Clustering Network (ESSN) and the Node Type indicator Routing protocol (NTIR). In order to reduce the service creation and execution time of the network, SIS collects the sensor values and with the help of the embedded adaptive rule based engine it develops the control signal directly according to the rules.

Green Home Energy Management System (GHEMS) [2] is introduced as a technology to reduce and manage home energy use. They claim that the feedbacks regarding the energy usage by consumers are the best solution to reduce the total energy use. Home appliances are connected to the electrical outlets. GHEMS determines the power and energy consumption of home appliances and convey the measured power and energy information to the home server through ZigBee network. The HEMS in the home server collects the energy consumption value from the electrical channels and shows hourly, daily, weekly, and monthly energy usage of home appliances. The electrical outlets determine the status (Switch on, Switch off, Stand by) of the home appliances.

HEMS which operates in the home server determines the gathered time of standby mode and normal mode. Then it informs the user regarding how long the device was used in the normal mode and related power consumed by that device during that time. The user thus receives the frequency and energy usage of each home appliance. Using the accumulated data from HEMS, the user can determine unnecessary energy waste in the standby mode and the operational energy used in the normal mode. HEMS also pops up a comparison chart of home appliances that is similar to other appliances. The user receives energy profile reference from energy portal service. The efficiency of the home appliances are very much related to the quality of supply voltage we are putting into the device. The Home Energy Management (HEM) [3] solution can offer efficient energy and real time budgeting information that enables users to optimize home energy use. Users can achieve visibility into household energy usage and manage how energy is utilized with the HEM.

The proposed work [4] is to model an energy based context, which is basically in relation to human context and their power consumption. It first analyzes the relationship between the context and each of its associated appliances and later each of its capability to generate energy saving schemes. Energy Saving service in a smart home can often be attained by turning off an appliance that is not presently used or by turning the working mode of an appliance to a more energy proficient one. This methodology saves almost 25% of energy by eradicating energy-waste situations at homes' every day. In an energy based context power consumption of a device is categorized into explicit and implicit power consumption. Explicit power consumption is closely related to human activity with a device. Implicit power consumption refers to appliances that are not directly related to human activity**.**

In the above research work [1] the complexity of the system increases with an increase in components such as SIG and SIS and these components are needed in every room. GHEMS [2] shares every home's appliances usage pattern to the external world without taking proper security measures and by doing so the usage pattern of appliances are vulnerable to security breaches. . But our proposed system uses WEEMAN based on the number of switch boards in a room to control all appliances inside HAN.

## III. Architecture Design

In today's electrical grid, power wastage has been so high due to the careless handling of home appliances by consumers. One of the major reasons for this issue is due to a lack of a system for coordinating the load operation and for controlling the energy consumption. The wireless devices are connected to each and every load for monitoring and controlling the consumption at home. The main components of this architecture as shown in the Figure 2 are smart meter and WEEMAN. In HAN, whenever a load is switched ON, it tries to communicate with the smart meter. Every load using the proposed hardware [WEEMAN] communicates with each other and with smart meter.

In our home area network, the smart meter works as a master node and it is used to collect the consumed power from all other devices and also calculate the total power utilized by the resident. The smart meter as shown in the figure 4 also functions as an interface between the resident and the utility company. From the utility company, it will collect the information of current Time of Use (TOU); depending on TOU, smart meter will calculate possible operating time for each device based on an algorithm called availability based management algorithm.

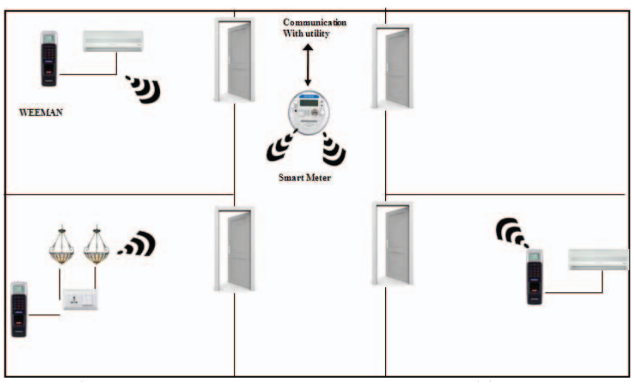


Figure 2 .Home Energy Management Architecture

### A. *WEEMAN [Wireless Enabled Electricity Manager]*

WEEMAN will be placed in every room beside every switch board and we are able to connect eight devices simultaneously. As shown in Figure 3 the hardware contains sensors (ACS 714) to sense the load currents there by calculating the power drawn by every appliance in the PIC microcontroller. The PIC will give a unique notation to every appliances attached to it and wirelessly send this unique id and power consumption value to the smart meter using low power 2.4 GHz module CC2420 [7] zigbee transceiver. During the time of installation consumer will give the name of the appliance to WEEMAN and later it will be communicated to smart meter. Every WEEMAN will be in direct range with smart meter and will update the smart meter when ever consumer uses any appliance or if there is a change in consumed power value. The WEEMAN will control the appliance using relays and relay driver IC as per the decision from the central unit called smart meter.

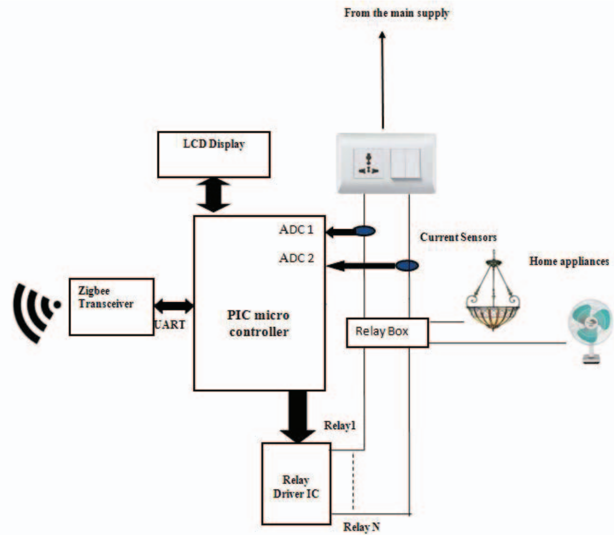


Figure 3.Wireless Enabled Electricity Manager

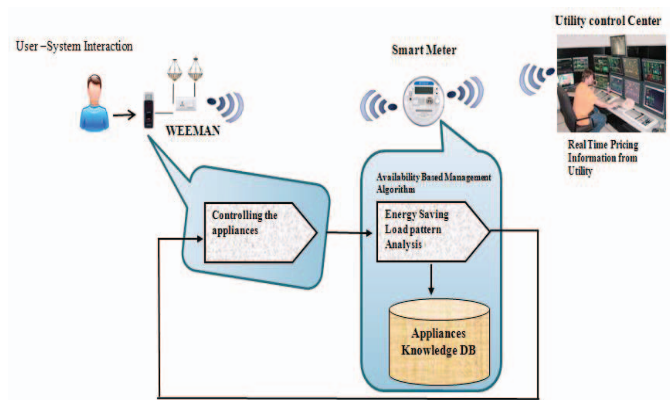


Figure 4 .Workflow diagram

### B. *Avilabilty Based Management Algorithm*

The home energy management system generally has different functions such as controlling the energy consumption at peak times, updating customers about the real time power consumption inside the home area network, and helping the customer to schedule the operation of their appliances based on real time pricing from the utility company. The proposed algorithm enhances the existing home energy management feature and helps the consumer to supervise their monthly budget. The algorithm collects input from consumers in the form of monthly current bill and controls the operation of all the appliances in HAN. There will be a minimum amount that the consumer can enter as their electricity budget. This depends on the number of appliances at home and the connection type. The algorithm always provides importance to user priority by analyzing the usage of appliances by the consumer.

The algorithm scrutinizes the user's priority by categorizing the appliances based on the frequency of use per month, the times of day the appliance is used and the consumer's preference. The utility company can also benefit from the algorithm in case a user utilizes extra power supply that is beyond their limit from the grid. The smart meter notifies this to the utility company, and they can impose a penalty for extra power consumption. The operation of the algorithm is basically the communication between different modules which is explained using a flow chart in figure 5.

*B.1. User interrupts*

The module "User Interrupts" will be activated whenever a user gives inputs and it passes the information to evaluation and decision making modules. The main user input the algorithm receives is the amount of monthly electricity bill. If the consumer has not set any amount, then the algorithm seeks the previous month's electricity bill amount. The user can set a priority for each appliance and set of desirable load from smart meter also through this module. The algorithm gives consumer the administrative power and he or she can always bypass the algorithm's decision in an emergency with the help of this module. When the user inputs the amount, the algorithm calculates the total number of energy units for a month ($u_m$) that the user can utilize based on the real time pricing from the utility company. Later the units will be sent to the evaluation module. Whenever WEEMAN and smart meter communicate with each other, that data is updated in real time.

*B.2. Real time data handling*

The updated real time data manages messages from WEEMAN; the contents of the message will be WEEMAN id, appliance id, power value of the appliance and name of the appliance. WEEMAN will send a message to smart meter whenever there is a change in the power value. Also at the time of initial set up, WEEMAN will also send information about the priority of different appliances set by the user. When smart meter receives this message, it will update the database with field's appliance id, power value, switch off/on time stamp and the status (on/off) and activates the decision making module. This database will be useful to analyze the usage pattern of the appliance and the time of use as a future reference. The module will also interact with the external utility company to collect information regarding real time pricing.

*B.3. Evaluation*

Evaluation regarding type casting of home appliances in to different categories (Continuous, Reserved, User priority and Delayable) will be done periodically. Evaluation module performed periodically in every day and later performed based on the behavioral change in the consumer towards the usage of appliances in their daily life. The assumption is that we have already learnt about the previous month's usage pattern of all the appliances and the algorithm knows about every appliance inside the HAN. The appliances are divided into regular load, reserved load, and user priority load. The algorithm assumes that every load in the HAN will be categorized in either of the above classification. If an appliance seems to be operating above 80 % of days in a month, then the algorithm groups it as regular load. Similarly, appliances that are being used between 40 % - 80% / day then it is grouped as a reserved load. For example, some user will operate appliances such as a vacuum cleaner, grinder etc only on some specific day or days in a week. The algorithm will store that data in memory and we receive the monthly-allotted units from the user interrupt module. The monthly-allotted units ($u_m$) are again divided into daily-allotted units ($u_d$), continuous units ($u_c$) and reserved units ($u_r$). Allocation depends on the monthly average operational time ($ot_{avg}$) of specific days (Sunday, Monday, .Saturday) based on the previous month's usage pattern of the appliances and the number of regular and reserved loads on that day. The algorithm reserves some units from the regular and reserved loads for the day and it is called as reserved units ($u_r$). In case the user doesn't use the daily or reserved units for a day then it will be added into free units ($u_f$) at the end of every day. User can take some units as credit from the following days during emergency conditions in the form of borrowed units ($u_b$) if there are no free units are available.

*B.4. Decision making*

If any user switches on any appliance, real time data manipulation module will inform that to the decision making module with appliance id. The module will check the category of newly arrived appliance in the database. If the appliance is classified as a regular or reserved load on that day then the algorithm permits to switch on the appliance up to the expected operational time for the day. The algorithm will decrement the units from the allotted reserved units based on consumption. If the appliance is not a reserved or regular load for that day then the algorithm will check for free units in the account. The algorithm allows the appliance to work up to the maximum allotted free units if there is availability. During circumstances such as the appliances are marked as user priority load and there are no free units available, the algorithm will search for any appliance, which is operating at the moment that can, start working later. The algorithm will delay the operation of such appliances whose power consumption is similar to the new appliance. It will help the algorithm to incorporate the real time demand for an appliance, without disturbing the unit's distribution.

In case there is no such delayable load at that moment, the algorithm gives an option to the consumer to operate the appliance on demand instantaneously by switching off some other loads, whose demand is less compared to the current appliance on demand. It will also help users to keep the power consumption of the residence within the stipulated limit. The algorithm waits for the user to select appliances to switch off from the display screen to accommodate their demanded load. If the user does not want to switch off any appliance, then the algorithm accepts the user's demands and borrows some units from the upcoming days to meet the extra demand. The units will be borrowed only based on the user's permission and depending on the availability of free units in the subsequent days of the previous month. Later the credited units will be nullified from the free units. At the end of the day free units will be updated if the consumer has not used the reserved units for that day.

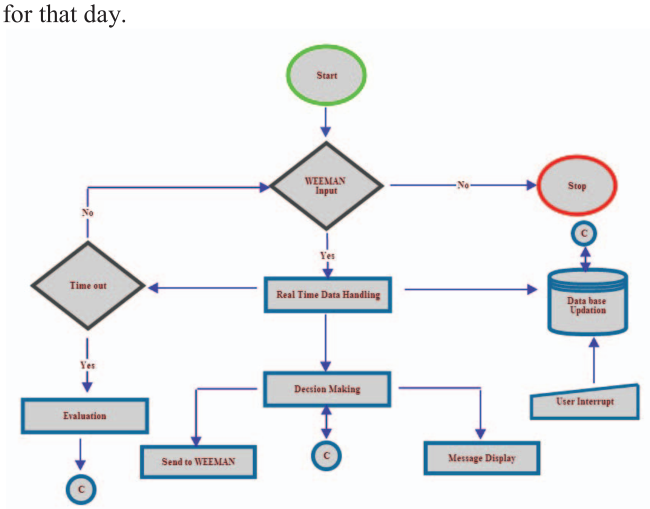


Figure 5. Flow chart

*C. Mathematical Analysis of Algorithm*

The algorithm starts with receiving consumers expected monthly electricity bill .Then algorithm calculates monthly allowed energy units ($u_m$) from that amount

if $A$ = Monthly current bill amount given by the user

$D$=Days of amonth(28,29,30or31)

$C(t)$ = Real time pricing for a unit from utility side

$$u_m = \frac{A}{D} \times \sum_{t=0}^{T} C(t) \qquad (1)$$

Where t is the real time varries based on Peak and

off peak time

Based on the previous month usage pattern of the appliances algorithm calculates $U_m$ from

$P_{avg}$ = Average power of a home appliance in KW

$t_{avg}$ = Average monthly opertational time of an appliance

$$U_m = \sum_{d=1}^{D} \left( \sum_{i=1}^{I} ot_{avg} * p_{avg} \right) \qquad (2)$$

*where* i and d are the number of appliances and number of

days in a month respectively

The algorithm always cross checks the values between $U_m$ and $u_m$ , makes sure that $u_m$ value is in within a certain range of $U_m$ .ie

$$U_m - \Delta u \;\le\; u_m \;\ge\; U_m + \Delta u \qquad (3)$$

If $u_m$ is not comes in range of $U_m$ then algorithm gives a warning message to the consumer that appliances inside the HAN is out of hand with the amount entered by the consumer.

Later algorithm allots units for each day in a month from $u_m$ based on the equation

$$u_m = \sum u_{d1} + u_{d2} \ldots\ldots\ldots\ldots\ldots\ldots. u_{dn} \qquad (4)$$

The value of $u_d$ will be equal to

$$u_d = u_f + u_b + \sum_{d=1}^{D} (u_c + u_r) \qquad (5)$$

## IV. Experimentation Setup

The designed hardware model for WEEMAN is shown in Figure 6. The loads [Home appliances] are connected with WEEMAN through a relay switch and relay module. The message and alarm notification for the customer will be displayed in the LCD interface provided in WEEMAN. For creating an experimental test bed, we have connected mainly a 200 W Incandescent Bulb [Load A] and a Table fan [Load B] with the WEEMAN. When we switch on both the loads simultaneously as shown in figure 6, the WEEMAN calculates the power consumed and sends it to the controlling station [smart meter]. By that time smart meter takes monthly electricity bill using a GUI created in lab view as shown in the figure 7.

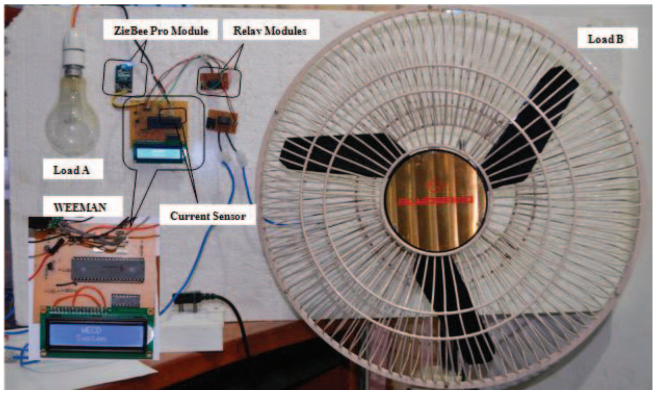


Figure 6. Experimental test bed using WEEMAN

Upon receiving the power value from WEEMAN the smart meter runs the availability based energy management algorithm and updates the database to categorize the loads. With this experimentation set up based on the monthly current bill given by the user, the algorithm detects a violation in consumption of units. In this scenario the user has given load A as a higher priority than load B. So the smart meter sends a message including load B's device id and delay time value to WEEMAN. .

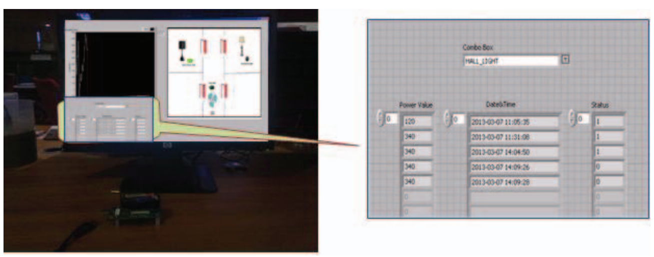

Figure 7 .Smart meter GUI for user input

When WEEMAN receives a message, it identifies the load to be switched off based on the device id received from the smart meter and switches off load B. Load B will be switched on again, when time elapses during the stipulated time of delay When the load is switched off and on by WEEMAN it will display the messages on the LCD as "Bulb is OFF" "Bulb is ON" and "Total Power consumption is 40 W"etc.

## V. Conclusion And Future Work

The proposed architecture and communication terminology enables consumers' to control the house hold electricity use and efficiently manage their monthly current bill. Also it enables the utility company to lessen the discrepancy between the demanded and generated power. The delay optimization between WEEMAN and smart meter, and protection of architecture against central node (smart meter) failure is going to be our future work.

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